Piezooptical constants of Rochelle salt crystals

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Abstract

The influence of uniaxial mechanical pressure applied along the principal axes and the corresponding bisectors on the birefringent properties of Rochelle salt (RS) crystals are studied. The temperature (77-300 K) and spectral (300-700 nm) dependencies of the effective π^0_{im} and absolute π_{im} piezooptical constants of the RS crystals are calculated. The intercept of dispersion curves of π_{im} is revealed in the region of the birefringence sign inversion. This testifies that the anizotropy of the piezooptical constant tensor decreases there. The temperature dependencies of absolute piezooptical constants do not manifest notable anomalies in the region of phase transitions of the Rochelle salt

Key words: uniaxial mechanical pressure, birefringence, combined and absolute piezooptical constants

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Elastooptical properties of the Rochelle salt (RS) crystals have been investigated by different authors. Those properties have been measured for the first time by Pockels [1] who determined only the order of magnitude for three of 12 piezooptical constants, namely the constants π_{44}, π_{55} and π_{66}. Using the technique of localized interference bands, Narasimhamurty have determined the whole matrix of the absolute piezooptical constants at T = 27°C (orthorhombic symmetry) for the yellow sodium spectral line [2]. Temperature variations of the effective piezooptical constants in the RS crystals measured with the half-wave voltage technique have been completely studied in the [3, 4].

The aim of this investigations is to determine the temperature (77-300K) and spectral (300-700 nm) dependencies of the absolute piezooptical constants of the RS crystals.

The influence of the uniaxial pressure on the temperature and spectral variations of the birefringence was studied with registering the changes in the interference pattern obtained with the spectrograph DFS-8. The instrument provides spatial resolution of extrema of different orders.

It was determined that uniaxial pressure σ_m (m = X, Y, Z) leads to different character and values of the Δn_i changes. For example, the Δn_z birefringence increases by 4.1×10^{-5} at the pressure σ_x = 150 bar but decreases by 3.9×10^{-5} in the case of the pressure σ_x = 150 bar. It is revealed that the pressure sensitivity of Δn_i increases with decreasing wavelength.

In the RS crystals, an inversion in the birefringence sign (IBS) exists along the X-axis (the direction of the acute bisector between the optical axes) [5]. The action of the uniaxial pressure σ_x or σ_z leads to similar behaviour of the birefringence Δn_x ($\delta\Delta n_x$ = 2.2×10^{-5} for σ_z =150 bar, and -2.9×10^{-5} for σ_x =150 bar). At room temperature, the sign of birefringence changes (Δn_x = 0) in the non-stressed sample at λ=285 nm. The pressure σ_z shifts the IBS point towards the long-wavelength region (Δn_x=0 at λ=270 nm), while in the case of the pressure σ_x the IBS point shifts towards the long-wavelength region (Δn_x=0 at λ=308 nm). A significant increase in the pressure sensitivity of Δn_x is observed in the spectral region of the IBS (δΔn_x = 6.9×10^{-5} at σ_z =150 bar, and -6.5×10^{-5} at σ_x =150 bar for T = 294K and λ=300 nm). The phenomenon will be discussed below.

The effective difference of piezooptical constants was calculated using the formula

$$\pi^0_{im} = \frac{2\delta\,\Delta\,n_i}{\sigma_m} - 2\Delta\,n_i\,s_{im} \qquad (1)$$

where $\delta\Delta n_i$ is the induced birefringence for the light propagation direction parallel to the i axis, σ_m the mechanical pressure along the m axis, i and m the principal axes of the optical indicatrix, and s_{im} the elastic coefficients. The second term in formula (1) describes the contribution caused by the pressure-imposed changes in the sample dimensions along the light propagation direction. The s_{im} data for the calculations are given in the papers [6, 7].

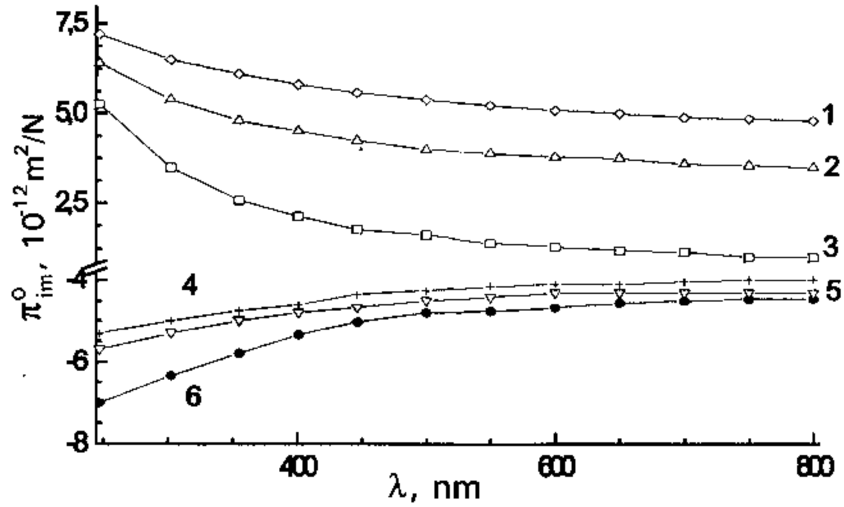

Fig.1. Dispersion of the combined piezooptic constants of Rochelle salt crystal at T = 298K: *1* - π^0_{32}; *2* - π^0_{23}; 3 - π^0_{13}; 4 - π^0_{21}; 5 - π^0_{31}; 6 - π^0_{12}..

Dispersion dependencies of π^0_{im} at room temperature are shown in fig. 1. The sign of π^0_{im} is considered as positive if the birefringence Δn_i increases under the influence of the pressure σ_m. As is seen from the figure, the π^0_{32}, π^0_{23} and π^0_{13} coefficients are positive, while the π^0_{12}, π^0_{31} and π^0_{21} are negative. The absolute values of π^0_{im} change with decreasing wavelength, i.e. a pronounced dispersion of piezooptical constants occurs. Probably, the dispersion is caused by the fact that, under the action of the uniaxial pressure, the shift of the fundamental absorption edge (in the RS crystals at the room temperature it is located at λ=247 nm) takes place in the vicinity of that edge. This leads to a notable dispersion of π^0_{im}.

Especially strong dispersion is observed in the case of the π^0_{13} and π^0_{12} constants:

$d\pi_{13}^{0}/d\lambda$ = –3.3×10^{-2} Br/nm and $d\pi_{12}^{0}/d\lambda$ = 1.5×10^{-2} Br/nm. The piezooptical constants π_{13}^{0} and π_{12}^{0} correspond to the changes in the birefringence Δn_x under the influence of the uniaxial pressures σ_x and σ_z. Since an IBS exists in x - direction in the RS, notable increase of π_{12}^{0} and π_{13}^{0} within the spectral range of the IBS may testify about a significant increase in the sensitivity of IBS with respect to the uniaxial pressures.

Temperature dependencies of the π_{im}^{0} coefficients for the RS crystals are shown in fig. 2. All the measured constants exhibit insignificant anomalies in the course of the PT, specifically a slight change in the curve slopes is observed.

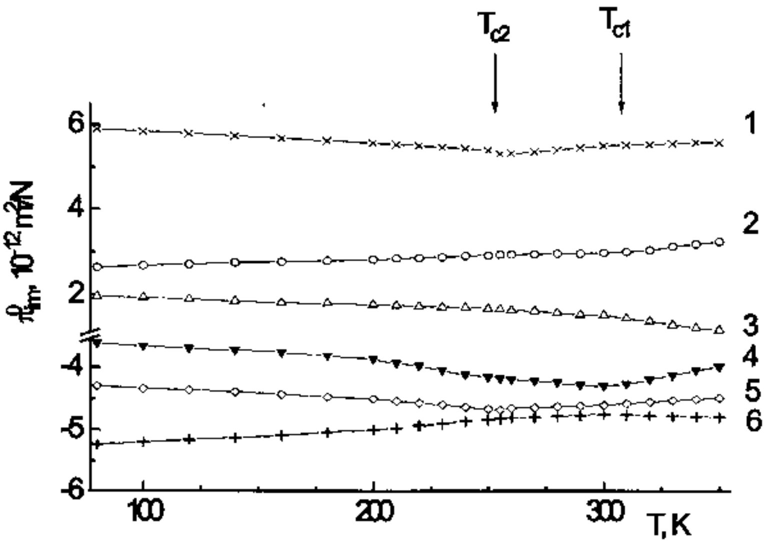

Fig. 2. Temperature dependences of combined piezooptic constants of Rochelle salt crystal for λ=500 nm: *1* - π_{32}^{0}; *2* - π_{23}^{0}; 3 - π_{13}^{0}; 4 - π_{21}^{0}; 5 - π_{31}^{0}; 6 - π_{12}^{0}.

In the paraelectric phase (T<255K and T>297.5K) the crystal structure is described by the point symmetry group 222, so that we have used the reported temperature and spectral dependencies of the effective piezooptical constants for the RS crystals, as well as the known relations for the piezooptically induced birefringence in the orthorhombic crystals (the ordinary Pockels' method [1]) in order to calculate the spectral and temperature dependencies of the absolute piezooptical constants of the RS crystals.

For this aim we have solved the system of nine equations of the following type:

$$\pi_{im}^{0} = \frac{n_m^3 \pi_{mm} - n_j^3 \pi_{jm}}{2} \qquad (2)$$

where the π_{im} are the unknown quantities, n_i, n_j and n_m the absolute refractive indices for the given light wavelength and temperature are used from the reference [8].

The dispersion dependencies of the absolute piezooptical constants π_{im} in the RS crystals are shown in fig.3. As it is seen from the figure, the dispersion of the piezo-constants is normal, and is equal to $d\pi_{im}/d\lambda$ =3.3, 7.5 and 6.0 for im = 11, 21, 31 (that being corresponding to the pressure σ_x), 4.0, 2.8 and 3.2 for im = 12, 22, 32 (the pressure σ_x) and 3.7, 0.9 and 1.5 for im = 13, 23, 33 (the pressure σ_z), respectively.

It is worthwhile to point out a following interesting detail. The extrapolation of the curves π_{23} and π_{33} (the same about π_{32} and π_{22}) into the short-wavelength region yields in their intersection, i.e. to their equality in the region 280 nm. This corresponds to the spectral position of the IBS at the room temperature.

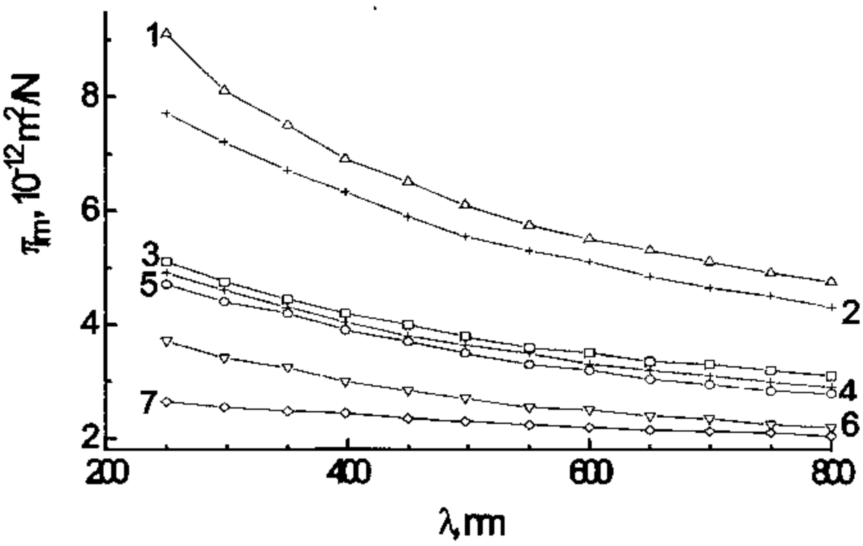

Fig.3. Dispersion of the absolute piezooptic constants of Rochelle salt crystal at T=298K: 1 - π_{21}; 2 - π_{31}; 3 - π_{12}; 4 - π_{11}; 5 - π_{32}; 6 - π_{23}; 7 - π_{33}.

The piezooptical constants π_{23} and π_{33} are responsible for the variation of refractive indices n_y and n_z under the action of the pressure σ_z. Those refractive indices determine the birefringence Δn_x in the direction of the IBS. Quite similarly, the constants π_{23} and π_{32} determine the variation of n_y and n_z when σ_x is acting. Thus, a decreasing of the anizotropy of piezooptical constant tensor occurs in the vicinity of the IBS, the phenomenon which has been earlier detected in the LiKS0$_4$ crystals [9].

Fig. 4 represents the temperature dependence of the absolute piezooptical constants of the RS crystals for the wavelength λ=500 nm. It is clearly seen that the anomalies in π_{im} (T) are practically not revealed at the upper PT. The anomalies in π_{im} (T) in the course of the lower PT are insignificant. In general, the π_{im} are only slightly temperature dependent, except for the π_{21} and π_{31}.

The absence of the pronounced anomalies in π_{im}(T) for the RS crystals are easy to explain using the relationships, which describe the anomalies of piezooptical constants:

$$\delta\pi_{im} = -\frac{2}{n_i^3}\frac{\delta n_i^s}{\sigma_m} = -\frac{2}{n_i^3}\frac{dT_c}{d\sigma_m}\frac{dn_i^s}{dT} \qquad (3)$$

The coefficients $dT_c/d\sigma_m$, which characterize the shift of the PT point under the pressure, are equal to 0.005 K/bar. The spontaneous polarization and spontaneous electrooptical effect determining the value of dn_i^s/dT at the PT are also insignificant. This is why the value $d\pi_{im}$ turns out to be small and is of the order of magnitude comparable with the experimental accuracy for π_{im}.

Hence the temperature dependencies of the π_{im} coefficients in the RS crystals are mainly caused by the "true" piezooptical contribution and, consequently, do not have any remarkable step-like anomalies.

Thus, we have revealed that the birefringence in the RS crystals is sensitive to the uniaxial pressure along the principal axes of optical indicatrix. Less sensitivity is characteristic with respect to the pressure directed along the directions of the corresponding bisectors. The calculated spectral dependencies of the effective and absolute piezooptical constants of the RS crystals manifest a notable dispersion in the ultraviolet spectral region. This is caused by the influence of uniaxial pressure on the position of the fundamental absorption edge. We have detected

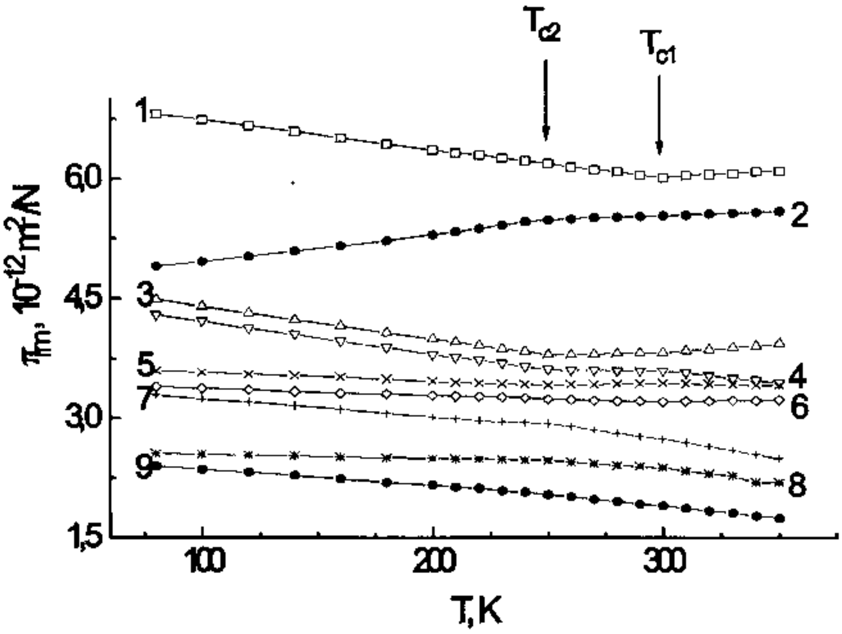

Fig.4. Temperature dependences of absolute piezooptic constants of Rochelle salt crystal for λ=500 nm: 1 - π_{21}; 2 - π_{31}; 3 - π_{12}; 4 - π_{11}; 5 - π_{13}; 6 - π_{32}; 7 - π_{22}; 8 - π_{23}; 9 - π_{33}.

the intersection of the dispersive curves π_{23} and π_{33}, as well as π_{22} and π_{32}, in the region of the birefringence sign inversion, which testifies that the anizotropy of the piezooptical constant tensor of a rank four becomes lower within the region of the isotropic point. The temperature dependencies of the absolute piezooptical constants do not reveal clearly expressed anomalies in the region of the PT in RS, thus testifying the fact that the temperature dependences of the π_{im} coefficients originate mainly from the "true" piezooptical contribution.

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